Geologic Map of the Union Hills 7.5' Quadrangle, Maricopa County, Arizona

by

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INTRODUCTION

The Union Hills 7.5-minute Quadrangle is located in the Phoenix metropolitan area. The quadrangle is located north of downtown Phoenix and is bordered by Paradise Valley to the north and east, and the Phoenix Mountains to the south (Figure 1). The quadrangle is bounded by latitudes 33°37'30"N and 33°45'00"N, and longitudes 112°00'00"W and 112°07'30"W. The area south of the Union Hills has become highly urbanized during the last few decades and is still undergoing rapid population growth. Thus, the knowledge of the distribution and character of bedrock and surficial deposits is important to make informed decisions concerning management of the land and its resources.

Geologic mapping of the Biscuit Flat Quadrangle is related to other 1:24,000 scale mapping projects in and around the Phoenix metropolitan area (Figure 1; see map plate). Geologic mapping of bedrock in the quadrangle was based on field mapping, whereas surficial mapping was based upon field observations, and the interpretation of aerial photographs and soils maps. The respective mapping coverage accomplished by each author (i.e., Holloway and Leighty) is shown on the map plate. A limited amount of unpublished Arizona Geological Survey mapping (by Steve Reynolds and Mike Grubensky for the Phoenix North 1:100,000 scale geologic map) augmented the new mapping of this report. Also, the 1:24,000 scale mapping of Tertiary rocks by Jagiello (1987) is locally similar to that of this report. Aerial photography includes a series of black-and-white, 1:20,000-scale (dated 1-19-70) and 1:40,000 scale (dated 9-6-92) photos. Soil information was compiled from USDA Maricopa County soil surveys (Hartman, 1977; Camp, 1986). This project was supported by the Arizona Radiation Regulatory Agency, with funds provided by the U.S. Environmental Protection Agency through the State Indoor Radon Grant Program, the U.S. Geological Survey via the STATEMAP and EDMAP programs, and the Arizona Geological Survey. Support of Stephen Holloway was also provided by the Department of Geology, Arizona State University.

PREVIOUS STUDIES

Although several workers have described the Proterozoic and Cenozoic rocks and structures in the region, detailed study of the Union Hills area has been relatively limited. The Proterozoic geology of the region has been summarized (Karlstrom et al., 1987; Karlstrom and Bowring, 1988, 1991; Anderson, 1989a,b; Karlstrom et al., 1990; Reynolds and DeWitt, 1991), but more detailed studies have typically concentrated in the Transition Zone to the north and east (Maynard, 1986, 1989; Bryant, 1994; DeWitt, unpublished mapping; Grubensky, unpublished mapping; Reynolds, unpublished mapping). The geology of the Phoenix Mountains and Paradise Valley areas are described in more detail (Schrader, 1919; Aylor, 1973; Shank, 1973; Cordy, 1978; Cordy and Pewe, 1978; Holway, 1978; Holway et al., 1978; Thorpe and Burt, 1978; Thorpe, 1980; Thorpe and Burt, 1980; Shank and Pewe, 1994; Jones, 1996). Geologic studies of adjacent areas to the west and north of the Union Hills Quadrangle have emphasized the Tertiary rocks and structures (Gomez, 1978; Gomez and Elston, 1978; Elston, 1984; Jagiello, 1987; Leighty et al., 1995; Leighty and Reynolds, 1996; Leighty, 1997). The uranium potential of Tertiary sedimentary deposits of the region was described by Scarborough and Wilt (1979), some of which are considered potential radon hazards (Duncan and Spencer, 1993; Harris, 1997; Harris et al., 1998). The Union Hills area is also included in mapping of the 1:100,000 scale Phoenix North 30' x 60' Quadrangle (Demsey, 1988; Reynolds and Grubensky, 1993). This report is contiguous with 1:24,000 scale geologic mapping recently completed in and around the Phoenix metropolitan area, including the Hedgpeth Hills (Leighty and Huckleberry, 1998a), Biscuit Flat (Leighty and Huckleberry, 1998b), New River SE (Leighty and Holloway, 1998), Cave Creek (Leighty et al., 1997), Wildcat Hill (Skotnicki et al., 1997), New River Mesa (Ferguson et al., 1998), and Humboldt Mountain (Gilbert et al., 1998) Quadrangles.

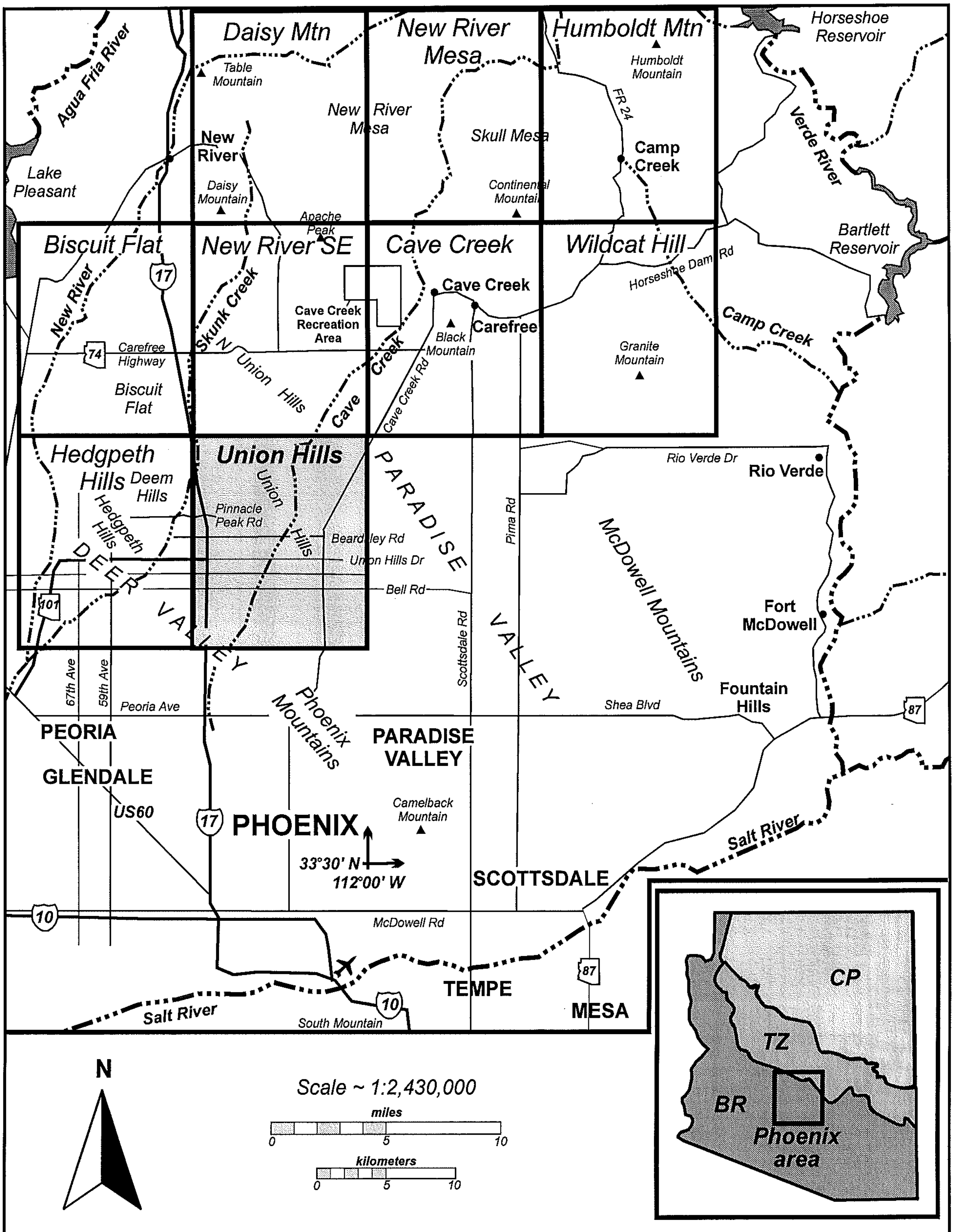

Figure 1. Location of the Union Hills 7.5' Quadrangle in the Phoenix region. The inset map shows the location of the study area relative to the three physiographic provinces in Arizona: the Basin and Range (BR), Transition Zone (TZ), and Colorado Plateau (CP).

PHYSIOGRAPHY

Arizona can be divided into three physiographic/geologic provinces (Figure 1): the Colorado Plateau, the Transition Zone, and the Basin and Range. The Union Hills Quadrangle lies within the Basin and Range province in central Arizona, where the terrain includes NW-trending mountain ranges separated by alluvial valleys. The northern Phoenix area includes several fault-bounded, NE-dipping, mountain ranges consisting of highly eroded Proterozoic and Cenozoic rocks. Paleozoic and Mesozoic rocks are absent in this area. The valleys are commonly filled with Cenozoic "basin-fill" sedimentary rocks and surficial deposits, with normal faults typically covered by alluvium.

The Union Hills Quadrangle includes small ranges and hills, piedmonts with coalescing alluvial fans, and broad alluvial plains (Figure 2). Topographic relief in the Union Hills ranges up to 800 feet, whereas the western and eastern areas of the quadrangle are predominantly low relief alluvial surfaces, forming Paradise Valley and Deer Valley. Prominent drainages include Cave Creek and Skunk Creek. Cave Creek is the largest stream in the area and flows south from its headwaters in the Transition Zone to the north. Vegetation across the area is typical of the Sonoran Desert, with various desert grasses, ocotillo, brittle bush, creosote bush, buckhorn and teddy bear cholla, and other types of cacti, including saguaro.

Overall, the access for the Union Hills Quadrangle is excellent (Figure 2). Numerous paved roads (e.g., Interstate 17, Cave Creek Road, Bell Road, etc.) and well-maintained dirt roads make much of the quadrangle highly accessible, although the area covered by private property is extensive. Much of the western part of the area is accessible from Interstate 17 (I-17), whereas Cave Creek Road and 36th Street provide access to the eastern areas. Numerous other paved roads (e.g., Happy Valley Road, Pinnacle Peak Road, Deer Valley Drive, Union Hills Drive, etc.) and well graded dirt roads are also present. Although the area adjacent to the Central Arizona Project (CAP) canal is restricted, the canal can be crossed at several locations. Access to Cave Creek Dam, Cave Buttes Dam, and the Cave Buttes Recreation Area (closed) within the Union Hills is restricted by several locked gates. Written permission can be obtained from Maricopa County Flood Control to unlock gates to the south of Cave Buttes Dam and on Jomax Road (intersecting with Cave Creek Road to the east of Cave Creek Dam). Much of the Union Hills is State Trust Land and is open to the public, but vehicle use requires permission from the State Trust Department. Access to the Union Hills from the west and north is possible over high clearance two-wheel drive and four-wheel drive dirt and bedrock roads. Building construction is active across the area, with the housing developments limiting access to previously accessible areas. Incipient construction along Happy Valley Road and Cave Buttes Road obscures the Quaternary surfaces, but provides excellent graded dirt and paved roads to the southwestern flank of the Union Hills and base of Cave Buttes Dam, respectively. Many of these new roads lead to, or replace, older established jeep roads.

PROTEROZOIC GEOLOGY

The Union Hills Quadrangle includes Early Proterozoic metavolcanic, metasedimentary, and intrusive rocks, and Early to Middle Proterozoic granitic to dioritic rocks. Similar Proterozoic lithologies are also exposed in nearby quadrangles (Anderson, 1989b; Reynolds and DeWitt, 1991; Reynolds and Grubensky, 1993; Leighty et al., 1997; Leighty and Huckleberry, 1998a,b; Leighty and Holloway, 1998). The metamorphic and plutonic rocks of these quadrangles are part of an Early Proterozoic terrane that contains rocks having similar age, metamorphic grade, and deformational fabrics, largely correlative with the Tonto Basin Supergroup and Diamond Rim Intrusive Suite (1740 to 1680 Ma; Anderson and Guilbert, 1979; Maynard, 1986, 1989; Reynolds et al., 1986; Anderson, 1989a,b; Conway and Silver, 1989). The metavolcanic and metasedimentary rocks of this terrane are distinctly different in lithology, petrology, chemistry, and geologic setting from rocks of the Yavapai Supergroup (1800 to 1740 Ma), exposed north of the Moore Gulch fault zone in the Transition Zone (Anderson, 1968; Reynolds et al., 1986; Karlstrom et al., 1987; Karlstrom and Bowring, 1988; Anderson, 1989b; Karlstrom et al., 1990).

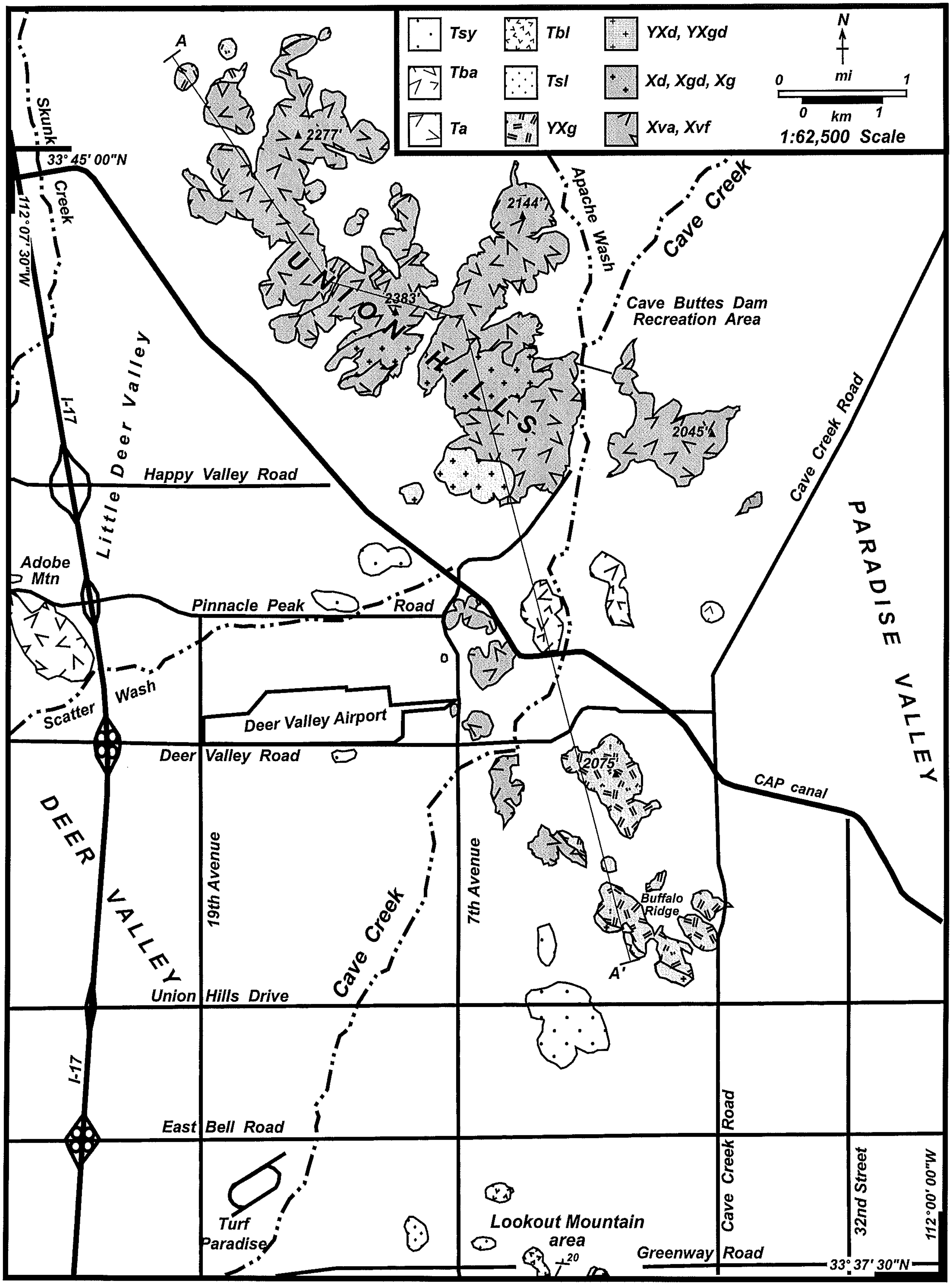

Figure 2. Generalized bedrock geology of the Union Hills Quadrangle with significant landmarks and roads.

Regional stratigraphy: the Tonto Basin Supergroup and related rocks

The Tonto Basin Supergroup was probably formed between 1740- and 1700-Ma, deformed largely between 1700- and 1650-Ma, and intruded by pre-1700-Ma granite and hypabyssal rocks (Karlstrom et al., 1987; Reynolds et al., 1986; Anderson, 1989a,b; Conway and Silver, 1989; DeWitt, 1989; Karlstrom et al., 1990) Reynolds and DeWitt, 1991). Although the stratigraphy and nomenclature are still controversial, the Tonto Basin Supergroup includes four major groups (from oldest to youngest): Union Hills Group, Alder Group, Red Rock Group, and Mazatzal Group (Anderson, 1989a,b; Conway and Silver, 1989; Reynolds and DeWitt, 1991).

- The Union Hills Group is the oldest unit of the Tonto Basin Supergroup, but is distinctly younger than the Yavapai Supergroup. The Union Hills Group is composed of: 1) mafic, intermediate, and felsic volcanic rocks and related tuffs, that were deposited in proximity to submarine volcanic centers, and 2) intermediate composition volcanic and volcaniclastic rocks and sediments deposited distally from major volcanic centers (Anderson, 1989b).
- Except for plutons coeval with the Union Hills Group volcanism, pre-1720-Ma plutonic rocks are effectively absent. The earliest major batholiths are the 1710 to 1700 Ma granites (e.g., Verde River granite) associated with ignimbrites of the younger felsic complexes (Reynolds et al., 1986).
- The Alder Group (1720-1710 Ma) is composed largely of clastic metasedimentary rocks (e.g., purple shale, quartzite) and felsic volcanic rocks. Alder Group volcanism may have occurred largely in shallow seas (Gastil, 1958; Conway, 1976; Conway and Silver, 1989).
- The Red Rock Group is a thick sequence of felsic extrusive rocks (i.e., alkali rhyolite ash-flow tuffs) overlying the Alder Group in the Tonto Basin and Mazatzal Mountains (Ludwig, 1974; Conway, 1976; Wrucke and Conway, 1987). Felsic magmatism was broadly contemporaneous with quartz arenite deposition in the upper part of the Alder and Mazatzal Groups. The Red Rock Group was probably deposited subaerially (Gastil, 1958; Conway, 1976; Conway and Silver, 1989).
- Relatively mature quartzite and other siliciclastic rocks of the Mazatzal Group (Wilson, 1939; Anderson and Wirth, 1981; Anderson, 1986) are the youngest part of the Tonto Basin Supergroup. This thick sequence of quartz arenite is fundamentally of continent-margin character and was deposited in fluvial and shallow-marine environments (Krieger, 1965; Trevena, 1979; Wirth, 1980; Anderson and Wirth, 1981; Conway et al., 1981; Conway and Silver, 1984).

Early Proterozoic rocks of the Union Hills area

The Union Hills Quadrangle contains a diverse assemblage of Early Proterozoic rock types. The metamorphic rocks of the Union Hills area are dominantly highly foliated metavolcanic rocks (greenschist facies or lower), with minor psammitic to pelitic metasedimentary rocks. Granitic to dioritic intrusive bodies are also present. These rocks have been described as part of the Union Hills Group, an assemblage of dominantly mafic to intermediate volcanic rocks and related sediments (1740 to 1720 Ma) that are exposed across the region, from the Union Hills and Cave Creek areas to the Mazatzal Mountains and Sierra Ancha to the northeast (Anderson, 1989b; Reynolds and DeWitt, 1991).

Metavolcanic rocks. The Union Hills contains a well-preserved sequence of highly foliated, greenschist facies metavolcanic rocks, including andesitic, basaltic, and dacitic flows, and rhyolitic to andesitic tuffs. Thick sequences of basaltic andesite to andesite lavas are interbedded with thinner dacite, rhyodacite, iron formation, andesitic tuff, and breccia units. All of these units are laterally interbedded with variably thick sequences of andesitic graywacke. Epidote alteration is common in the volcanic rocks, as well as in the felsic and intermediate intrusions.

The meta-andesite and metabasalt (Xva) are typically fine- to medium-grained, aphyric to subporphyritic lavas that commonly have plagioclase phenocrysts in a fine-grained chloritic groundmass. Original amphibole and pyroxene have been altered to biotite. Olivine phenocrysts are absent from most lavas, except for those in the southeasternmost part of the Union Hills. The lava flows can be mesoscopically heterogeneous, with chilled margins, microdioritic cores, and vesicular flow tops. Quartz veins are abundant and more silicic lenses, selvages, and pods are common. The flows are locally interbedded with cogenetic pelitic to psammitic sedimentary beds, volcaniclastic breccias, and tuff. Locally altered meta-andesitic lithic tuffs (Xvat) are micaceous, laminar to thinly bedded, with brown carbonate lenses, red-purple ferruginous chert veins (1-15 mm wide) and silicic selvages. Andesitic or basaltic pillow-shaped masses are locally exposed that are 30-60 cm in diameter and have vesicular rinds and hyaloclastic haloes (Figure 3). Lavas with these pillow structures signify subaqueous eruption, and can often be used to define stratigraphic orientation. The pillow lava exposures scattered across the Union Hills generally indicate stratigraphic top to the northwest.

Dacitic to rhyolitic metavolcanic rocks are also present in the Union Hills area. The felsic metavolcanic rocks (Xvf) include highly foliated, fine-grained metarhyolite that is commonly interbedded with metarhyolitic tuff. Medium-grained, highly foliated dacitic metavolcanic rocks (Xvd) weather in a blocky fashion, forming large (10-100 cm) subrounded boulders. Metadacite also occurs as thin (1-20 m wide) layers or dikes(?) in the more mafic-intermediate volcanic rocks. Lithic-rich rhyolitic tuff (Xvft) is compositionally homogeneous, with feldspar and quartz phenocrysts, and quartz augen present locally. This unit is typically massive, white, chalky, and very micaceous, but also forms a highly foliated, quartz+muscovite schist. Hydrothermally altered zones are commonly rich in hematite, limonite, goethite, and ilmenite. Local bedding may indicate subaerial deposition for this tuff unit.

Metasedimentary rocks, ferruginous chert, etc. Dark gray, weakly to moderately foliated, pelitic to psammitic rocks (Xs) are interbedded with the intermediate to mafic volcanic rocks in the Union Hills area. These metasedimentary rocks consist of poorly sorted, angular to subangular quartz and feldspar grains in a fine-grained chloritic matrix (i.e., graywacke). Very fine-grained ferruginous chert/iron formation (Xfc) forms dark, discontinuous, resistant ridges, typically only a few meters wide. Rare lenses (10-50 cm thick) of stretched pebble conglomerate and ferruginous breccia are also present. These sedimentary rocks were likely deposited in a relatively deep submarine environment proximal to the volcanic center. Overall, the metasedimentary rocks and ferruginous chert, along with the metavolcanic rocks, are equivalent to rocks of the Union Hills Group of Anderson (1989b). Similar fine-grained metasedimentary and phyllitic rocks are exposed to the northeast, in the Cave Creek Quadrangle, and possibly represent a more distal facies of the Union Hills units (Anderson, 1989b; Leighty et al., 1997). Across the region, the Alder Group disconformably overlies rocks of the Union Hills Group. However, Alder Group rocks are not exposed in the Union Hills Quadrangle.

Plutonic rocks. Several foliated, medium- to coarse-grained plutonic units are present within the metavolcanic sequence within the Union Hills, including porphyritic granite (Xgp), granite (Xg), and granodiorite (Xgd). These plutonic rocks are geochemically similar to the volcanic rocks (Anderson, 1989b) and may have fractionated from a more mafic calc-alkaline parent magma (related to eruption of the mafic to intermediate lavas) before intrusion into the volcanic pile. As with the volcanic rocks, the exact age relations of the plutonic rocks are not well constrained. However, Anderson (1989b) and Reynolds and DeWitt (1991) have compared the mineralogy and geochemistry of some of the granodioritic and dioritic plutonic rocks to the Bland quartz diorite (1719 ±9 Ma; Bowring et al., 1986) and the Bumblebee-Badger Springs Granodiorites (1740 ±10 Ma; Anderson et al., 1971). These rocks could have also been produced by a slightly younger period of plutonism that occurred during and after deposition of the 1725 to 1710 Ma Alder Group sedimentary rocks.

Early to Middle Proterozoic plutonic rocks of the Union Hills area

Relatively unfoliated plutonic rocks include coarse-grained granite (YXg), diorite (YXd) and granodiorite to diorite (YXgd). The coarse-grained granite is present at the northwestern end of the Union Hills, and in the Buffalo Ridge area. This rock includes microcline, plagioclase, quartz, and subhedral biotite. The granite weathers into large spheroidal boulders and erodes easily into grus that mantles the granitic bedrock. This unit is correlative with granitic rocks exposed to the west in the Biscuit Flat and Hedgpeth Hills Quadrangles that have been informally referred to as the granite of Pyramid Peak (Reynolds and DeWitt, 1991; Leighty and Huckleberry, 1998a,b). Diorite (YXd) and granodiorite-diorite (YXgd) are present in the central part of the quadrangle. In the southern Union Hills, these rocks intrude older, more foliated metavolcanic rocks. The diorite includes large knobs of older metavolcanic rock and is more mafic at the contact with the metavolcanic rocks. The diorite includes plagioclase, quartz, biotite, and amphibole. The unfoliated, medium- to coarse-grained granodiorite to diorite is compositionally similar to the diorite unit (YXd), but includes areas with more abundant microcline. The contact between the dioritic and granodioritic phases ranges from gradational to sharp.

The coarse-grained granite is likely correlative with the large granite batholith (1422-Ma, C. Isaacson, pers. comm.) exposed to the northeast, and other megacrystic granites (1425 to 1335 Ma) in Arizona (Silver, 1968; Livingston and Damon, 1968; Reynolds ete al., 1986). However, it is possible that this unfoliated granite is a post-tectonic Early Proterozoic. The exact age relations of the diorite and granodiorite-diorite units are more speculative. These rocks clearly crosscut the metavolcanic rocks, but it is unclear whether they are 1) slightly younger Early Proterozoic intrusions or 2) a more mafic, comagmatic facies of the coarse-grained granite.

Proterozoic structural features

The primary foliation across the quadrangle is typically N- to NE-striking and steeply NW-dipping, consistent with the orientation of the main foliation in rocks of similar age in other parts of the region (e.g., Mazatzal Mountains, Phoenix Mountains, Gila Bend Mountains). Foliation is defined by alignment of mica grains, minor segretation of felsic and mafic minerals, and cleavage. Cleavage is best expressed in the phyllitic rocks and is typically parallel or slightly discordant to bedding. A secondary foliation exists locally in the intermediate to mafic metavolcanic rocks. This foliation appears as a horizontal shear zone that cuts across the primary vertical foliation. The dominant regional vertical NE-trending foliation is likely due to a NW-trending compressional event, likely subduction-related, that correlates to the main orogentic event of the Transition Zone, the Yavapai Orogeny (1710 to 1695 Ma) and/or Mazatzal Orogeny (1675 to 1650 Ma). The secondary horizontal foliation indicates episodic deformation and may represent crustal extension in the Proterozoic or may be related to local intrusion activity.

The Union Hills area contains subvertical to vertical, tight to isoclinal, NE-plunging folds. Large scale (100-1000 m), megascopic folds of metavolcanic and hypabyssal plutonic rocks are exposed in the central portion of the Union Hills. Fold axes are parallel to primary foliation. Less competent layers (i.e., tuffs) are highly contorted near contacts with more competent metavolcanic and intrusive rocks. Discontinuous ferruginous chert layers may represent bedding, but are sheared apart near fold axes, forming distinctive 'J' hooks.

Proterozoic Geologic Summary

- Union Hills Group volcanism and sedimentation likely occurred between 1745-Ma and 1720-Ma. Volcanism involved a compositionally diverse suite (basalt, basaltic andesite, andesite, dacite, and rhyolite) that may have originally formed a submarine eruptive complex. Fine-grained clastic rocks and tuffs were deposited in and around the eruptive complex and in a surrounding deep-water basin.

- The 1700 to 1690 Ma Yavapai Orogeny involved crustal shortening, thickening, and uplift which generated the north- to northeast-striking subvertical foliation that is the dominant fabric in central Arizona (Karlstrom and Bowring, 1991).
- Largely undeformed Middle Proterozoic granitic rocks were emplaced into the Arizona crust between 1485-Ma and 1380-Ma (Silver et al., 1977; Anderson, 1989). These 'anorogenic' granites are part of an extensive belt of granitic batholiths extending from the mid-continent region to the Mojave Desert (Anderson, 1983; Dickinson, 1989). The coarse-grained granite in the Union Hills area is likely part of the granitic batholith exposed between Cave Creek and the Mazatzal Mountains.

CENOZOIC GEOLOGY

Cenozoic rocks of the Union Hills Quadrangle include isolated outcrops of Late Oligocene to Late Miocene basaltic rocks, andesite, conglomerate, and basin-fill sediment. Pleistocene to Holocene alluvial and colluvial deposits are more extensive and cover much of the quadrangle.

Tertiary rocks

Many of the tilted, fault-block ranges in the Phoenix area Basin and Range contain Tertiary lithologic sequences similar to those exposed in the southern part of the Transition Zone. These sequences include Oligocene to Early Miocene rocks (e.g., prevolcanic fanglomerate, Chalk Canyon formation) and Middle Miocene mesa-capping basaltic flows (e.g., Hickey Formation). Isolated Late Miocene basin-fill clastic sediments are also locally exposed near bedrock ranges. However, there are relatively few outcrops of Tertiary basaltic and sedimentary rocks in the Union Hills Quadrangle. Although voluminous ash-flow-related volcanism occurred across southern Arizona during the Middle Tertiary, rocks representing this volcanism are not exposed in the Union Hills area.

Older sedimentary rocks. Middle Tertiary conglomeratic sediments (Tsl) are exposed beneath Early Miocene basaltic lavas in the Lookout Mountain area. These sediments are largely covered by an apron of colluvium, talus, and Middle Pleistocene sediments surrounding Lookout Mountain. This crudely bedded pre-basalt conglomerate typically forms the base of the Chalk Canyon Formation sequence and may correlate with other Middle Tertiary clastic deposits in the Phoenix area.

Basaltic rocks. A small number of isolated exposures of basaltic lavas are present across the Union Hills Quadrangle. Although the age relations of these rocks are poorly constrained, the basaltic petrography and geochemistry may allow rudimentary correlation with basaltic to andesitic rocks atop several fault-block remnants (e.g., Shaw Butte, Deem Hills, Hedgpeth Hills, Carefree Highway Range) in the Phoenix area (Leighty, 1997).

A sequence of basaltic lavas and breccias (Tbl) cap Lookout Mountain at the south-central quadrangle boundary. These resistant, dark gray, lavas are aphyric to olivine-phyric and may be somewhat altered. No tuffaceous rocks are exposed in the section, but several scoriaceous basaltic breccia horizons are present which represent the boundaries between lava flows. The age of the lowermost basalt flow near the summit is 19.20 ±0.47 Ma (Shafiqullah et al., 1980). Thus, the basaltic rocks exposed at Lookout Mountain are likely equivalent to the lower member of the Chalk Canyon formation, which represents a regionally extensive association of interbedded Early Miocene basaltic lavas, tuffs, and fluvial-lacustrine sediments (Lindsay and Lundin, 1972; Eberly and Stanley, 1978; Gomez, 1978; Gomez and Elston, 1978; Shafiqullah et al., 1980; Jagiello, 1987; Leighty et al., 1995; Leighty, 1997). Early Miocene basaltic lavas (23 to 20 Ma) and felsic tuff dominate the lower member of the Chalk Canyon formation (Lindsay and Lundin, 1972; Eberly and Stanley, 1978; Gomez, 1978; Leighty et al., 1995; Leighty, 1997).

Lavas that are possibly correlative with the Middle Miocene Hickey Formation are exposed at Adobe Mountain and in the small hills in the central part of the quadrangle. The andesitic lavas (Ta) at Adobe Mountain are largely buried by desert-varnished andesitic talus. These dark gray porphyritic lavas contain glassy plagioclase phenocrysts and resorbed quartz inclusions. In the Hedgpeth Hills Quadrangle to the west, this andesite overlies a Chalk Canyon formation basalt-tuff sequence and Middle Miocene Hickey Formation basaltic rocks (e.g., Ludden Mountain, Hedgpeth Hills), but also underlies Chalk Canyon formation conglomeratic sandstone and tuffaceous units (e.g., Deem Hills). Basalt to basaltic andesite rocks (Tba) are exposed near the center of the quadrangle in several hills near Union Hills Drive. These dark grayish brown to dark gray lavas are characteristically intergranular to porphyritic in overall texture, with altered olivine phenocrysts present in a framework of plagioclase crystals. Similarities with other lavas in the region (Leighty, 1997) suggest that these lavas are probably subalkaline in chemistry (olivine-subalkali basalt and basaltic andesite), but hornblende is locally present that may indicate a more silicic composition (e.g., basaltic andesite to andesite).

The Union Hills area basaltic and andesitic lavas were likely produced by the same Middle Miocene eruptive event that formed other Hickey Formation lavas across this part of the Basin and Range (Eberly and Stanley, 1978; Gomez, 1978; Elston, 1984; Jagiello, 1987; Leighty and Glascock, 1994; Leighty, 1997). These lavas have also been referred to as the New River Mesa Basalt (Gomez, 1978; Jagiello, 1987). In the Biscuit Flat quadrangle to the west, a mesa-capping flow north of the Ben Avery Shooting Range has been dated at 15.39 ±0.4 Ma (Scarborough and Wilt, 1979).

Younger sedimentary rocks. A few, poorly exposed, colluvium-covered exposures of "basin-fill" sediments (Tsy) are present in the central portion of the quadrangle (e.g., near the Deer Valley airport, southwest of Buffalo Ridge). Exposures along 16th St are clast-supported and poorly sorted, with rounded to subrounded cobble- to boulder-sized clasts. Clast compositions include abundant Proterozoic granite, granodiorite, and diorite. Tertiary basaltic clasts have aphyric, olivine-phyric, and intergranular textures. The medium- to coarse-grained sandstone matrix is calcareous, with variable amounts of hematite. These rocks were likely deposited during and after Late Miocene extensional tectonism.

Tertiary extensional tectonism

Tertiary extensional tectonism significantly affected the Phoenix area, forming the distinctive Basin and Range physiography. Across the region, Early Miocene extension was fundamentally different in magnitude, style, and orientation compared with the Middle to Late Miocene normal faulting. However, in the north Phoenix area, there are similarities in the style and orientation of the two extensional phases.

Middle Tertiary. Following relative tectonic quiescence of the Early Tertiary, significant extensional tectonism occurred across the Arizona Basin and Range during the Middle Tertiary (Late Oligocene and Early Miocene), and has been referred to as the "mid-Tertiary Orogeny" (Damon, 1964). The Transition Zone and Colorado Plateau did not experience significant upper crustal extensional deformation during this time, but the reversal of regional drainage and formation of the Mogollon Rim was a likely effect of middle to lower crustal deflation in response to extension in the adjacent Basin and Range (Spencer and Reynolds, 1989). Middle Tertiary tectonism was dominantly characterized by ENE-WSW-directed extension along low-angle normal faults (or detachment faults) and subsequent fault-block rotation, typically related to metamorphic core complex development (Coney, 1973; Davis and Coney, 1979; Coney, 1980; Crittenden et al., 1980; Davis, 1980; Wernicke, 1981; Reynolds, 1982; Davis, 1983; Davis et al., 1983; Lister and Davis, 1983; Reynolds, 1985; Reynolds and Lister, 1987; Spencer and Reynolds, 1989). Middle Tertiary extension in Arizona was broadly related to the evolving plate-tectonic setting of the continental margin of western North America (Atwater, 1970), and more specifically to changes in plate motions and geometries compounded by overriding of the progressively thinner and hotter subducted Farallon plate (Coney and Reynolds, 1977; Coney, 1978; Damon, 1979).

In south-central Arizona, initiation of extension-related tilting occurred before or during felsic volcanism (~ 25 to 20 Ma) and generally ended before 17-Ma, except in a NW-trending belt adjacent to the relatively unextended Transition Zone (Fitzgerald et al., 1994; Spencer et al., 1995). Movement on detachment faults related to the South Mountain-White Tank composite metamorphic core complex yielded relatively large amounts of Early Miocene extension (Spencer and Reynolds, 1989). The South Mountain detachment fault is visible on seismic reflection profiles (Frost and Okaya, 1986) and projects to the northeast beneath the NE-tilted fault-block ranges of the upper plate of the core complex (Spencer and Reynolds, 1989). This area of generally unidirectional, NE-tilting in the Basin and Range has been referred to as the Camelback tilt-block domain (Spencer and Reynolds, 1989). These NE-dipping tilt-blocks (e.g., the Union Hills) were likely rotated along large, SW-dipping normal faults that are antithetic to the NE-dipping South Mountain detachment fault. In the Union Hills Quadrangle, the Lookout Mountain Tertiary sequence dips ~20° NNE, but any related fault structures are covered by Late Cenozoic sedimentary deposits. These normal faults may be listric in geometry to account for the fault-block rotation. It is likely that the Union Hills structural block also formed by movement along one or more (listric?) normal faults that are now covered by post-faulting sediments. Well-log and and detailed gravity data are sparse, so the subsurface geometry of much of the quadrangle is not well-constrained. However, existing gravity data suggests that the area underlain by Deer Valley is not a significant basin.

During the Early and Middle Miocene, synextensional basaltic lavas, sedimentary rocks, and tuffs of the Chalk Canyon formation (23 to ~15 Ma) and Hickey Formation (16 to <10 Ma) were erupted/deposited across central Arizona. Hickey Formation sheet lavas may have extended across the much of the northern Phoenix area, where the youngest dated lavas are 15.4-Ma in the eastern Biscuit Flat Quadrangle. Similar lavas cap many of the other ranges in the Phoenix area. Accordingly, the NE-directed tilt-block rotation occurred sometime after 15.4-Ma (and possibly <13.4-Ma), probably with movement along large, possibly listric, SW-dipping normal faults. This extension may have been related to waning metamorphic core complex extension and/or block faulting of the Basin and Range Disturbance (Menges and Pearthree, 1989; Leighty and Reynolds, 1996). However, the post-15.4-Ma rotation of these fault-blocks is significantly younger than the inferred age of active metamorphic core-complex extension. Indeed, this rotational style of faulting may have overlapped to some degree with the beginning of high-angle normal faulting of the Basin-and-Range Disturbance (Menges and Pearthree, 1989; Leighty et al., 1996). To explain these relationships, it has been suggested that the long duration and magnitude of core-complex extension adjacent to the Transition Zone are consistent with a more passive mechanism of extension where the gravitational potential energy of the thicker Transition Zone crust caused southwest-directed collapse (Spencer et al., 1995).

Late Tertiary. The Basin-and-Range Disturbance represents a period of graben subsidence that occurred along high-angle normal faults, largely without major crustal block rotation. In the Arizona Basin and Range, it began ~15-Ma and ended ~8-Ma (Eberly and Stanley, 1978; Menges and Pearthree, 1989). Basin subsidence was probably not simultaneous, but mostly occurred before 8-Ma, when differential vertical movement essentially ceased, pediments formed, and basins filled (Shafiqullah et al., 1980). Newly created basins filled with undeformed fluvial and lacustrine deposits and basaltic rocks that were deposited over tilted beds deformed by earlier, mid-Tertiary normal faulting. Similar elevations of pediment gravel layers suggest that basin subsidence occurred with little or no change in the absolute elevation of the surrounding ranges (Peirce, 1976; Peirce et al., 1979). From well log and geophysical data, the depth of several of the large, deep Miocene basins (e.g., the Paradise Valley basin, Luke basin) in the Phoenix metropolitan area exceed 10,000 feet (Oppenheimer, 1980). Although the area is entirely covered by Quaternary surficial deposits, a significant gravity gradient parallels the trend of the Paradise Valley along the eastern border of the quadrangle (Lysonski et al., 1980; Oppenheimer and Sumner, 1980, 1981). The Paradise Valley basin, likely bounded by large, high-angle normal faults, is responsible for this geophysical anomaly.

Quaternary deposits

Quaternary surficial deposits cover much of the Union Hills Quadrangle. These deposits include alluvial fan, channel, and terrace units that range in age from Middle Pleistocene to Holocene. Similar units in the Phoenix region are described Demsey (1988) and Pearthree et al. (1997).

Piedmont deposits. These deposits are shed onto the broad plains that slope gently down from mountian ranges toward basin floors and include Middle Pleistocene to Holocene alluvium (Qy, Qylf, Ql, Qml, and Qm). These deposits are generally poorly sorted, containing particles that range in size from silt or clay to cobbles or boulders. Piedmont deposits grade or interfinger downslope into finer-grained deposits. The older alluvial deposits are estimated to be of Middle Pleistocene age (Qm) and are predominantly exposed marginal to the various bedrock ranges in the area. These sediments are typically extensively eroded, leaving rounded ridges between modern channels. Most Late Pleistocene and Holocene alluvium (Ql and Qy) is restricted to fairly narrow bands along washes. In the Paradise Valley area of the southeastern part of the quadrangle, fine-grained Late Pleistocene to Holocene alluvial deposits (Qlyf) form a thin, basin-covering veneer.

Major river deposits. Fluvial sediments include active channels and one or more terrace levels that record former, higher positions of the stream channels. These deposits are differentiated from piedmont deposits by their diverse lithologic composition, clast rounding, and landform morphology. In the Union Hills Quadrangle, these deposits are mainly related to the development of the Cave Creek drainage. Cave Creek drains a large, geologically diverse area, so its sediments have likely been transported a considerable distance before being deposited in this area. Thus, clasts are more rounded than those in piedmont areas. River terraces are also commonly elongate landforms that mimic the general trend of the modern rivers. This is evident all along the Cave Creek drainage system where several terrace and channel deposits (Qmr_1, Qlr, Qyr) are present where Cave Creek crosses Paradise Valley and the southeastern Union Hills. To the southwest of the Union Hills, the main Cave Creek drainage becomes less coherent as it crosses the low relief terrain of the Deer Valley area and comes very close to its base level (the Salt River lies in the next quadrangle to the south).

MINING

Throughout the Union Hills Quadrangle, small man-made pits are surrounded by tailings containing variable amounts of quartz, hematite, malachite, and chrysocolla. However, most present-day activity is related to sand and gravel quarrying from various Quaternary fluvial deposits. The coarse-grained granite exposed at the northwesternmost end of the Union Hills is mined for use as decorative landscaping material.

GEOLOGIC HAZARDS

Flooding is probably the most serious geologic hazard of the Union Hills Quadrangle. Potential flood hazards consist of inundation and erosion along Cave Creek, Skunk Creek, and their larger tributaries, and flash-flooding associated with the smaller tributary streams that flow across the piedmonts of the area. Cave Creek is a moderately large drainage that heads in the Transition Zone northeast of the Union Hills Quadrangle. Thus, Cave Creek is capable of generating large floods, and its principal tributaries can generate smaller, but still significant, 100-year floods. These floods involve deep, high-velocity flow in the channels, inundation of overbank areas, and may cause substantial bank erosion along the channels. Areas mapped as Qyc are likely to be affected by deep, high velocity flow during floods. Areas near the large streams covered by older deposits (Ql, Qlr, and older) generally are not subject to inundation, but they may be affected by lateral stream erosion. Tributary channels (Qy) are also likely to be subject to shallower inundation, and local bank erosion.

Flood hazards associated with smaller tributaries may be subdivided into: 1) localized flooding along well-defined drainages, where there is substantial topographic confinement of the wash, and 2) widespread inundation in areas of minimal topographic confinement (i.e., active alluvial fans). Delineation of flood-prone areas along well-defined drainages is fairly straightforward, and these hazards may be mitigated by avoiding building in or immediately adjacent to washes. Thus, the extent of young deposits (Qy) on piedmonts is an accurate indicator of areas that have been flooded in the past few thousand years. These are areas that are most likely to flood in the future. The Central Arizona Project (CAP) canal and several dams in the Union Hills area help to mitigate the damaging effects of tributary flooding.

Several types of soil/substrate problems may be encountered in the Union Hills Quadrangle. Soil compaction or expansion upon wetting or loading may be an important geologic hazard in limited portions of the quadrangle. Soil instability has caused extensive damage to buildings in Arizona (Christenson et al., 1978; Péwé and Kenny, 1989). Changes in soil volume beneath structures may cause damage ranging from nuisance cracks to serious structural damage. Deposits that are susceptible to compaction are typically relatively fine-grained, young sediments. Local deposits that are candidates for compaction are the fine-grained terrace deposits (i.e., Qy, Qyr, and Ql). Clay-rich soils associated with well-preserved Middle Pleistocene alluvial fans (Qo and Qm) may have some potential for shrinking and swelling during dry and wet periods, respectively. However, clay-rich horizons associated with these surfaces are generally less than 1 m thick, so their shrink-swell potential is probably limited. The presence of cemented caliche (petrocalcic soil horizons) or shallow bedrock may impact construction excavation and leaching potential. Calcium carbonate accumulates in soils in this desert environment over thousands to hundreds of thousands of years. Typically, the soils associated with Middle Pleistocene alluvium (Qm) in this area have significant accumulations of calcium carbonate, but strongly cemented carbonate soil horizons are not common. Petrocalcic horizons are found in some middle Pleistocene alluvium (Qm) and thin hillslope deposits (Qc). Progressively less carbonate accumulation is associated with increasingly younger surfaces, so Ql and younger deposits have weakly developed carbonate horizons.

Radon, a colorless, odorless, radioactive gas, can pose potential health problem in certain circumstances. Radon can escape from the ground into overlying homes and other buildings, and result in elevated radiation exposure, and associated risk of cancer, to human lungs. Radon is a decay product of uranium, so areas with higher uranium concentrations present greater risk of elevated indoor radon levels (Spencer, 1992). Uranium is present in all geologic materials, generally in concentrations of 1 to 10 ppm. The alluvial basin cover in the region is not a significant radon hazard, but certain types of bedrock can have highly variable concentrations of uranium (Duncan and Spencer, 1993). In the Phoenix area, lithologies that have demonstrated elevated uranium levels, thus posing a potential radon hazard, include certain Proterozoic granitic rocks and Middle Tertiary sedimentary rock (marl). Since much of the Union Hills area is covered by Quaternary deposits, radon is probably not a significant hazard in the area. The Chalk Canyon formation marl is not exposed in the Union Hills Quadrangle, but may be present at depth. Water wells may tap these uranium-rich rocks directly, but most wells are shallow and do not penetrate bedrock. Rocks having a moderate radon potential (1 to 13 ppm U) exist in the Carefree area to the northeast (Harris, 1997). Levels greater than 6 ppm U can be considered slightly anomalous. The high variability of uranium levels may be due to different amounts of leaching of uranium from weathered granite at or near the surface. The occurrence of local elevated uranium levels, plus the generally permeable character of weathered granite which allows radon to leak out of the ground (Peake and Schumann, 1991), indicate that elevated radon levels in homes built on this granite are probably more likely than on most other geologic materials in the Phoenix metropolitan area. Uranium levels (1 to 3 ppm) in the coarse-grained granite (YXg) in the Buffalo Ridge area are lower than some of the granitic rocks in the Carefree area (Harris, 1997; Harris et al., 1998). Proterozoic metamorphic rocks in the North Union Hills that are similar to those in the Union Hills have very low U concentrations (<<1 ppm) and are not a likely radon threat (Harris et al., 1998).

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UNIT DESCRIPTIONS

Quaternary piedmont deposits

Qct **Colluvium and talus, undivided (<750 ka)** - Unconsolidated to moderately consolidated colluvium and talus hillslope deposits. This unit typically includes subangular to angular, poorly sorted, sand- to boulder-sized clasts. Adjacent bedrock lithologies dominate the clast compositions. These deposits probably range in age from Holocene to Middle Pleistocene.

Qy **Holocene alluvium (<10 ka)** - Holocene alluvial deposits consisting primarily of small active channels, low terraces, and broad alluvial fans. This unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble, and boulder deposits confined to the modern tributary drainages of Cave Creek, Scatter Wash, and Skunk Creek. Alluvial surfaces exhibit bar-and-swale topography, with the ridges typically being slightly more vegetated. Qy surfaces are frequently mantled by sandy loam sediment, but have minimal or no rock varnish or desert pavement development. Late Holocene soils are minimally developed, but Middle and Early Holocene typically contain cambic horizons, weak calcic horizons (≤Stage I), and are noticeably reddened. Surface colors are light brown to yellowish brown, with a slight reddening with depth due to oxidation. Some of the older Qy soils may contain weakly developed argillic horizons. Qy soils are classified as Torrifluvents, Torriorthents, Camborthids, and Calciorthids. Because surface soils are not indurated with clay or calcium carbonate, Qy surfaces have relatively high permeability and porosity. All areas mapped as Qy may be subject to inundation during large floods.

Qlyf **Holocene to Late Pleistocene fine-grained alluvium (<100 ka)** - Relatively young, fine-grained sheet-flood and overbank deposits that mantle much of the lower piedmont area in the southeast part of the quadrangle and adjacent Paradise Valley. Urban development in this area precludes any delineation into separate units. Qlyf deposits contain sand, silt, and clay, with some fine gravel. This unit includes many small channels, but also typically surround younger Qy channels. Soil development is generally weak to moderate, consisting mainly of minor silt, clay, and carbonate accumulation (Stage I). Qlyf soils are classified as Torrifluvents, except where the deposits are thin (<50 cm) over older soils. Qlyf surfaces may be prone to flooding.

Ql **Late Pleistocene alluvium (10 to 250 ka)** - Late Pleistocene alluvial fan surfaces and terraces consisting of moderately sorted, clast-supported sandstone and conglomerate with abundant granitic or metamorphic gravel clasts in a tan to brown sandy to silty matrix. Ql surfaces are moderately incised by stream channels, but still contain constructional, relatively flat, interfluvial surfaces. Much of northern Deer Valley is covered by broad expanses of Ql deposits. Subdued bar and swale topography is common. Desert pavement and rock varnish development ranges from nonexistent to moderate. Surface colors are slightly more red (light brown to reddish yellow) than Qy surfaces. Ql soils are also more strongly developed than Qy soils. Ql soils commonly contain tan to red-brown argillic horizons that are weakly to moderately strongly developed. These soils typically have Stage II-III calcium carbonate development. Ql soils are classified as Haplargids, Camborthids, and Calciorthids. The low infiltration rates of these surfaces favor plants that draw moisture from near the surface. Ql surfaces are generally not prone to flooding, except immediately adjacent to active washes.

Qml **Middle to Late Pleistocene alluvium (10 to 750 ka)** - A composite map unit that contains both Middle Pleistocene (Qm) and Late Pleistocene (Ql) alluvial fan and terrace deposits. This unit occurs between Cave Creek and Skunk Creek and continues to the southwest. Farming and urban development preclude any delineation into separate units. Qml surfaces are not prone to flooding, except immediately adjacent to washes.

Qm **Middle Pleistocene alluvium (250 to 750 ka)** - Dissected Middle Pleistocene alluvial fan and terrace deposits that include sandy to loamy, tan sandstones and minor conglomerates with sand- to boulder-sized clasts. Qm surfaces have typically been eroded into shallow valleys and low ridges. Original depositional surfaces may be preserved along ridge crests. Desert pavement and rock varnish development is moderate to strong on stable surfaces, but variable to weak on eroded surfaces. Locally, Qm has been subdivided into older (Qm_1) and younger members (Qm_2). Qm soils are moderately to strongly developed, with surfaces ranging in color from dark brown to reddish brown and reddened argillic horizons moderately to strongly enriched in pedogenic clay. Calcic horizon development is fairly strong (Stage II-IV), but soils generally do not have cemented petrocalcic horizons (caliche). These soils are classified as Calciorthids and Haplargids. Qm surfaces are not prone to flooding, except near active washes.

Quaternary river deposits

Qycr **Active channel deposits (<1 ka)** - Deposits in the active channels of Cave Creek and Skunk Creek and their principal tributaries. Predominantly sand and silt, especially in areas subject to overbank flooding, with clasts ranging in size from pebbles to boulders. Clasts are subrounded to well-rounded and lithologies vary substantially. Distributary and anastomosing channel patterns are common. Most of the channel surfaces are modern in age, but vegetated bars may be several hundred years old. Alluvium in these deposits is typically well-stratified and lack any appreciable soil development. Qycr soils are typically classified as Torrifluvents or Torriorthents. Qycr surfaces are prone to flooding.

Qyr **Holocene river terrace deposits (0 to 10 ka)** - Low terrace deposits composed of unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Landforms typically are low terraces. Minor channels are common locally. Primary fluvial bedforms (gravel bars, fine-grained swales) near the surface are absent or weakly expressed due to bioturbation. These deposits have weakly developed soils that are light brown to yellowish brown on the surface, with a slight reddening with depth. There is typically organic accumulation in the uppermost soil horizons, with slightly oxidized horizons at deeper levels. Minimal or no rock varnish or desert pavement development. Weak calcic horizons (≤Stage I) are present in Middle and Early Holocene soils. Qyr terrace soils are Torrifluvents and Camborthids. Portions of Qyr surfaces have been inundated during historical floods, and lateral bank erosion is also a hazard.

Qlr **Late Pleistocene river terrace deposits (10 to 250 ka)** - Intermediate, moderately old terrace deposits of Cave Creek. Unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Soils have moderate clay accumulation and carbonate development (Stage II), but no cementation. Desert pavement and rock varnish is nonexistent to moderately developed. These surfaces are not prone to flooding, but lateral bank erosion may occur where proximal to active channels.

Qmr **Middle Pleistocene river terrace deposits (400 to 750 ka)** - Prominent, high, old terrace deposits of Cave Creek. Qmr alluvium is composed of unconsolidated sand, gravel, and cobble channel deposits with interbedded fine-grained overbank sediments. Some of the eroded Qmr landforms consist of low, rounded ridges and moderately incised stream channels. Desert pavement and rock varnish development is weak to moderate. Soils on Qmr terrace surfaces are strong brown to reddish brown and are strongly developed where they have not been highly eroded. Clay accumulation is variable, but well-preserved soils have strong, red argillic horizons with loam and clay loam textures. Well-developed calcic or petrocalcic horizons are also common (Stage III-V). Locally consists of a slightly older member (Qmr_1). Qmr terrace soils are classified as Calciortids, Paleorthids, and Paleargids.

Tertiary volcanic and sedimentary rocks

Tsy **Basin-fill deposits (Late Miocene to Pliocene)** - Interbedded, moderately to poorly sorted 'basin-fill' sandstone and conglomerate exposed in the central portion of the quadrangle, including in the vicinity of the Deer Valley airport and southwest of Buffalo Ridge. Exposures along 16^{th} St are clast-supported and poorly sorted, with rounded to subrounded clasts ranging in size from cobbles to boulders. Clast compositions include abundant Proterozoic granite, granodiorite, and diorite, as well as Tertiary basaltic clasts that include aphyric, olivine-phyric, and intergranular textures. The medium- to coarse-grained sandstone matrix contains is calcareous, with variable amounts of hematite. These rocks were likely deposited during and after the Middle Miocene extensional tectonism of the Basin and Range Disturbance.

Tba **Basalt to basaltic andesite (Early to Middle Miocene)** - Basaltic lava flows. Probably correlative to the Middle and Late Miocene Hickey Formation. Also referred to as the New River Mesa Basalt (Gomez, 1978; Jagiello, 1987). These dark grayish brown to dark gray lavas are characteristically intergranular to porphyritic in overall texture, with clinopyroxene and altered olivine phenocrysts present within a framework of plagioclase crystals. Olivine phenocrysts are typically altered to reddish orange iddingsite. From Leighty (1997), chemical compositions are largely subalkaline (olivine-subalkali basalt and basaltic andesite), as defined by their major element (e.g., SiO_2, Na_2O+K_2O) and normative mineral abundances (e.g., normative hypersthene >> diopside, quartz $\geq$ 0, and nepheline = 0). Hornblende is locally present and may indicate a more silicic composition (e.g., andesite). Columnar jointing and zones of vesicles are common in outcrop. The vesicles are open to calcite-filled and are 1-5 cm in diameter. These lavas were likely produced by the same Middle Miocene (16 to 14 Ma) eruptive event that formed other Hickey Formation sheet lavas across Transition Zone and Basin and Range (Leighty, 1997). This unit is exposed in three small hills located between Buffalo Ridge and Cave Creek. In the Biscuit Flat Quadrangle to the west, a mesa-capping flow is dated at 15.39 ±0.4 Ma (Scarborough and Wilt, 1979).

Ta **Andesite (Early to Middle Miocene)** - Andesite exposed at Adobe Mountain containing glassy plagioclase phenocrysts and resorbed quartz inclusions. In the Hedgpeth Hills Quadrangle, this andesite overlies the basalt-tuff sequence and Hickey Formation basaltic rocks (e.g., Ludden Mountain, Hedgpeth Hills), but also underlies conglomeratic sandstone and tuffaceous units (e.g., Deem Hills).

Tbl **Basaltic rocks (Early Miocene)** – Early Miocene (19.20 ±0.47 Ma; Shafiqullah et al., 1980) aphyric to moderately porphyritic olivine basalt flows exposed at Lookout Mountain. These dark gray lavas contain variably altered olivine phenocrysts in a very fine-grained groundmass.

Tsl **Conglomerate and sandstone (Late Oligocene to Early Miocene)** - Middle Tertiary conglomerate and sandstone exposed beneath Early Miocene basaltic lavas at Lookout Mountain. These sediments are largely covered by an apron of colluvium, talus, and Middle Pleistocene sediments surrounding Lookout Mountain. This crudely bedded pre-basalt conglomerate typically forms the base of the Chalk Canyon Formation sequence and may correlate with other Middle Tertiary clastic deposits in the Phoenix area.

Early to Middle Proterozoic plutonic rocks

YXg **Granite (Early to Middle Proterozoic)** - Coarse-grained, relatively unfoliated, porphyritic biotite granite. Includes light gray to light pink microcline (0.5-2 cm), light gray to white plagioclase (2-6 mm), clear gray quartz (2-8 mm), and subhedral black biotite (2-4 mm). Exposed at the northwesternmost end of the Union Hills. Correlative with granitic rocks exposed to the west in the Biscuit Flat and Hedgpeth Hills quadrangles that have been informally referred to as the granite of Pyramid Peak. This granite is possibly correlative with the large granite batholith exposed north of the McDowell Mountains to the east.

YXd **Diorite (Early to Middle Proterozoic)** - Relatively unfoliated diorite. Includes large (1-10 mm) white plagioclase, clear quartz, black biotite (1-3 mm), and amphibole. Includes large knobs of older metavolcanic rock. The diorite is more mafic at the contact with the metavolcanic rocks. Surface weathers to a pink-brown color. Exposed in the southeastern Union Hills and Buffalo Ridge areas.

YXgd **Granodiorite to diorite (Early to Middle Proterozoic)** - Unfoliated, medium- to coarse-grained granodiorite to diorite. Diorite phase contains subhedral phenocrysts of quartz (1-4 mm) and plagioclase (2-5 mm), and angular phenocrysts of amphibole and minor biotite. Surface is moderately weathered pink-brown. Breaks along joints. Granodiorite phase contains medium- to coarse-grained phenocrysts of clear white quartz (1-3 mm), minor white plagioclase (1-3 mm), pink microcline (3-8 mm), and black amphibole (1-4 mm). The contact between the two phases ranges from gradational to sharp. The diorite is distinguished from granodiorite by the higher mafic content. Exposed in the southeastern Union Hills.

Early Proterozoic plutonic rocks

Xgp **Granite porphyry (Early Proterozoic)** - Highly foliated, medium- to coarse-grained porphyritic granite. Contains phenocrysts of either plagioclase or quartz. Fine-grained quartz matrix with small (1-2 mm) laths of hornblende and local quartz augen. (5-15 mm). Exposed in the central Union Hills.

Xg **Granite (Early Proterozoic)** - Medium- to coarse-grained granite. Contains subhedral phenocrysts of clear white quartz (1-4 mm), white plagioclase (2-5 mm), pink microcline (3-5 mm), and biotite (2-5 mm). Aphanitic mafic xenoliths (1-10 cm) are present in zones or bands. Exposed in the central Union Hills.

Xgd **Granodiorite (Early Proterozoic)** - Medium-grained (3-10 mm) granodiorite with interstitial biotite. Contains roughly 10% minerals of mafic composition. Weathers to a grussy, light tan to dark reddish-brown surface. Exposed in the central Union Hills.

Early Proterozoic metamorphic rocks

Xva **Mafic to intermediate metavolcanic rocks (Early Proterozoic)** - Highly foliated, massive, fine- to medium-grained greenschist facies meta-andesite and basalt. More highly-foliated, slaty to phyllitic rock present locally. Andesitic rocks include granular plagioclase phenocrysts (1-3 mm) present in fine-grained, chloritic groundmass. Amphibole and pyroxene are altered to biotite. Thin (1-3 m) felsic and intermediate micaceous tuff beds are interbedded with the andesite. This unit weathers red, brown, orange, and green, with brown to black desert varnish. Zones of hydrothermal alteration. Foliation is very convoluted in places. The older NE-striking fabric, with parallel quartz veins (1-3 cm), is truncated by younger, horizontal fabric. Numerous carbonate veins (1-15 mm). Locally has andesitic or basaltic pillows (30-60 cm in diameter), with vesicular rinds, discontinuous pillow-shaped masses, and hyaloclastic haloes. Epidote is localized around quartz nodules. Metamorphic segregation produces local felsic and epidote-rich mafic banding. Also present are layers of quartz boudins, and a few thick (10-50 cm) quartz veins. Amphibole and pyroxene are altered to biotite.

Xvf **Felsic metavolcanic rocks (Early Proterozoic)** - Highly foliated and jointed, massive, fine-grained, meta-rhyolite, commonly interbedded with meta-rhyolite tuff. Exposed in the northwestern Union Hills.

Xvd **Dacitic metavolcanic rocks (Early Proterozoic)** - Highly foliated, blocky, medium-grained, meta-dacite. Occurs in thin (1-20 m) layers or dikes(?) in the more intermediate greenstone. Forms large (10-100 cm) sub-rounded boulders. Exposed in the central Union Hills.

Xvft **Metarhyolite tuff (Early Proterozoic)** - Lithic-rich rhyolitic tuff. Compositionally homogeneous, with feldspar and quartz phenocrysts, and quartz augen present locally. This unit is typically massive, white, chalky, and very micaceous. Commonly hydrothermally altered, with zones rich in hematite, limonite, goethite, and ilmenite. This unit also forms a highly foliated, quartz white mica schist. Contains thin (1-3 cm) interbeds of fine-grained felsic volcanic rock with quartz phenocrysts. Local bedding may indicate an air fall tuff origin. Exposed in the central Union Hills near Apache Wash.

Xvat **Meta-andesite tuff (Early Proterozoic)** - Micaceous, andesitic lithic fragmental rock. Typically exposed as slaty, brown linear ridges. Locally altered to white from acidic solution in hydrothermal zones. Laminar to thinly bedded with alternating bands of color. Brown carbonate and red-purple ferruginous chert veins (1-15 mm) and silicic selvages. Exposed in the central Union Hills near Apache Wash.

Xs **Metasedimentary rocks (Early Proterozoic)** - Weakly to moderately foliated, dark gray, firmly indurated, pelitic to psammitic rocks. Dominantly consists of poorly sorted angular to subangular quartz and feldspar grains (>60%) in a compact, chloritic matrix. Overall texture is granular with bands of more coarse (1-4 mm), angular grains. Outcrops weather white-tan, whereas fresh surfaces are dark gray. Contact with meta-andesitic rocks (greenstone) is sharp and undulatory. Also occurs as thin (5-20 cm) lenses within the meta-andesitic rocks. Exposed in the Union Hills and east of the Deer Valley airport.

Xfc **Ferruginous chert/Iron formation (Early Proterozoic)** - Dark, very fine-grained, discontinuous resistant ridges, typically only a few meters wide. Formed as a silica gel which infiltrates underlying volcanic layers. Quartz veins are abundant. Generally parallel to stratigraphy and locally folded to show geometry of major folds. Forms 'J' hooks near the hinges of major isoclinal folds, but hinge blows out and the accompanying limb is sheared off. Rare lenses (10-50 cm thick, 5-10 m long) of stretch pebble conglomerate and ferruginous breccia.

d **Disturbed area** - Areas of significant surficial disruption due to various human activities, including large sand and gravel quarries (e.g., along Cave Creek), Cave Creek Dam, Central Arizona Project canal, etc.